

Making Sense of the Particle Size Distribution Measurements



Purpose

To understand the theory behind the *Particle Size Distribution Measurements Protocol* and how the data can be used to predict percent sand, silt, and clay

Overview

Using the measurements made in the *Particle Size Distribution Measurements Protocol*, the amount of sand, silt, and clay in grams and in percent will be calculated. Students will also be introduced to the theory behind the settling experiment (Stoke's Law), and instructed on how to use the textural triangle with both the results from their measurements and a sample set of sand, silt, and clay measurements for practice.

Time

One class period

Level

Intermediate and Advanced

Key Concepts

How different particle sizes in the soil are distributed to create a specific texture

Stoke's Law and particle settling

Skills

Reading a conversion table

Using mathematics to correct hydrometer readings for volume and temperature

Calculating the amount of sand, silt and clay in grams and in percent of the sample

Reading information from a textural triangle

Estimating percentages

Materials and Tools

Data from Soil Particle Size Distribution Measurements Data Work Sheet

Copy of the textural triangle for each student

Ruler or straight edge

Preparation

Conduct a discussion of different size particles in soils and their distribution. See the Introduction.

Perform the *Particle Size Distribution Measurements Protocol* to obtain the measurements required for this exercise.

Background

The amount of each size particle (sand, silt, or clay) in the soil is called the particle size distribution. Knowing the particle size distribution of a soil sample helps us understand many soil properties including how much water, heat, and nutrients the soil will hold, how fast water and heat will move through the soil, and what kind of structure and consistence will form. Sand, silt, and clay are the 3 particle sizes of

mineral material found in soils. The amount of each of these is called the particle size distribution and the way they feel is called the soil texture.

Sand is the largest sized particle, silt is medium sized, and clay is the smallest. There is disagreement in the scientific community about the exact size ranges of sand and silt. For GLOBE, we will measure sand and silt based on 2 different size definitions:

1. The US Department of Agriculture (USDA) which defines the size of sand as 2.0 mm - 0.05 mm, and the size of silt as 0.05 - 0.002 mm.
2. The International Soil Science Society (ISSS) which defines the size of sand as 2.0 mm - 0.02 mm, and the size of silt as 0.02 - 0.002 mm.

Clays are the smallest particles and are defined (by both organizations) as being smaller than 0.002 mm. Particles greater than 2 mm are called stones or gravels and are not considered to be soil material.

Heavy, large particles settle first, so when a soil sample is stirred or shaken in a 500 mL cylinder, sand particles (according to the USDA definition) settle to the bottom of the cylinder after 2 minutes, while the clay and silt size particles stay in suspension. After 12 minutes, the sand, according to the ISSS definition, has settled, leaving the clay and silt size particles in suspension. After 24 hours, the silt size particles have settled, and only the clay stays in suspension to be recorded by the hydrometer.

To Determine the Amount of Sand, Silt, and Clay in Your Soil Sample

The specific gravity hydrometer is an instrument used to measure the density of water which has materials suspended in it compared with pure water. A hydrometer and temperature reading is made at 2 minutes, 12 minutes, and 24 hours during the *Particle Size Distribution Protocol*. To determine the amount of sand, silt, and clay in your sample, we will take each hydrometer reading and make a temperature correction to it. Next, we will use a conversion table (below) to convert the corrected specific gravity of the water to grams of suspended soil per liter (1000 mL) which includes a correction for the density of the dispersing agent that was added. Once we make that conversion, we need to multiply by the number of liters (0.5 L or 500 mL), in order to determine the number of grams of soil in suspension.

Obtain the data recorded on the Particle Size Distribution Measurements Data Work Sheet, and

use the Calculation Work Sheet below to perform the following corrections:

1. Begin with your 2 minute hydrometer reading. From the conversion table below, determine the value of grams of soil/liter. At 2 minutes, this value corresponds to the grams of silt (USDA size) plus clay in suspension. All of the sand (USDA size) has settled to the bottom of the cylinder.
2. Note the temperature values you obtained 2 minutes. For every degree of temperature above 20 °C, add 0.36 grams to the grams of soil you obtained from the table. Subtract 0.36 for every degree below 20 °C.
3. Next, multiply the value for temperature-corrected grams of soil/L by 0.5 L to find out how many grams of soil we have in suspension in the 500 mL cylinders. This answer gives you the grams of silt plus clay in your sample.
4. Repeat procedure 1, 2, and 3 for the 12 minute and 24 hour hydrometer readings using the temperature read at each time period to correct for every degree above or below 20 °C. The 12 minute reading corresponds to the amount of silt (ISSS size) plus clay that is in your sample (the ISSS sand has settled at 12 minutes). The 24 hour reading represents the amount of clay in your sample (all of silt and sand has settled by 24 hours).
5. To find out how many grams of sand (according to the USDA) you have in your sample, subtract the amount of silt plus clay you calculated in step 3 above by the original amount of soil you used in the GLOBE Particle Size Distribution Protocol (25 grams). The percent sand is equal to the grams of sand in the sample divided by 25 grams (the original amount of soil), and multiplied by 100 to get percent.
6. To calculate how many grams and the percent of sand (according to the ISSS), repeat step 5 for the grams of silt plus clay you obtained at 12 minutes.



7. The grams of clay in your sample is the amount of clay determined above from the corrected reading at 24 hours. Dividing the grams of clay by the original weight of the sample used (25 grams) will give the percent of clay in the sample.
8. The amount of silt can be calculated by adding the grams of clay (step 7) and sand (step 5 for USDA or step 6 for ISSS) together, and subtracting that amount from the weight of soil added to the cylinder (25 grams). The percent silt is determined by dividing the grams of silt by 25 grams, or by subtracting the sum of the percent sand plus percent clay from 100 percent.
9. Repeat these calculations for the samples from each horizon in your soil profile. Use the Calculation Work Sheet to help your work. You can compare your results with the final results that will be returned to you after you submit the raw data from your Particle Size Distribution Measurements Data Work Sheet to the GLOBE Student Data Server.
10. You can use the Textural Triangle procedure to determine the texture name of your sample that corresponds with the particle size distribution.

Table SOIL-L-1: Conversion Table (specific Gravity to Grams of Soil/L)

Specific Gravity	Grams Soil/L	Specific Gravity	Grams Soil/L	Specific Gravity	Grams Soil/L
1.0024	0.0	1.0136	18.0	1.0247	36.0
1.0027	0.5	1.0139	18.5	1.0250	36.5
1.0030	1.0	1.0142	19.0	1.0253	37.0
1.0033	1.5	1.0145	19.5	1.0257	37.5
1.0036	2.0	1.0148	20.0	1.0260	38.0
1.0040	2.5	1.0151	20.5	1.0263	38.5
1.0043	3.0	1.0154	21.0	1.0266	39.0
1.0046	3.5	1.0157	21.5	1.0269	39.5
1.0049	4.0	1.0160	22.0	1.0272	40.0
1.0052	4.5	1.0164	22.5	1.0275	40.5
1.0055	5.0	1.0167	23.0	1.0278	41.0
1.0058	5.5	1.0170	23.5	1.0281	41.5
1.0061	6.0	1.0173	24.0	1.0284	42.0
1.0064	6.5	1.0176	24.5	1.0288	42.5
1.0067	7.0	1.0179	25.0	1.0291	43.0
1.0071	7.5	1.0182	25.5	1.0294	43.5
1.0074	8.0	1.0185	26.0	1.0297	44.0
1.0077	8.5	1.0188	26.5	1.0300	44.5
1.0080	9.0	1.0191	27.0	1.0303	45.0
1.0083	9.5	1.0195	27.5	1.0306	45.5
1.0086	10.0	1.0198	28.0	1.0309	46.0
1.0089	10.5	1.0201	28.5	1.0312	46.5
1.0092	11.0	1.0204	29.0	1.0315	47.0
1.0095	11.5	1.0207	29.5	1.0319	47.5
1.0098	12.0	1.0210	30.0	1.0322	48.0
1.0102	12.5	1.0213	30.5	1.0325	48.5
1.0105	13.0	1.0216	31.0	1.0328	49.0
1.0108	13.5	1.0219	31.5	1.0331	49.5
1.0111	14.0	1.0222	32.0	1.0334	50.0
1.0114	14.5	1.0226	32.5	1.0337	50.5
1.0117	15.0	1.0229	33.0	1.0340	51.0
1.0120	15.5	1.0232	33.5	1.0343	51.5
1.0123	16.0	1.0235	34.0	1.0346	52.0
1.0126	16.5	1.0238	34.5	1.0350	52.5
1.0129	17.0	1.0241	35.0	1.0353	53.0
1.0133	17.5	1.0244	35.5	1.0356	53.5
				1.0359	54.0
				1.0362	54.5
				1.0365	55.0



Calculation Work Sheet

- A. 2 minute hydrometer reading _____
- B. temperature at 2 minutes _____ °C
- C. grams/L of soil (USDA silt + clay) from table _____ g/L
- D. temperature correction $[(0.36 \times (B - 20^\circ \text{C}))]$ _____ g
- E. corrected silt (USDA) and clay in suspension (C+D) _____ g
- F. grams of soil (USDA silt + clay) in 500 mL $(E \times 0.5)$ _____ g
- G. grams of sand (USDA) $(25 \text{ g} - F)$ _____ g
- H. percent sand (USDA definition) $[(G/25) \times 100]$ _____ %**
- I. 12 minute hydrometer reading _____
- J. temperature at 12 minutes _____ °C
- K. grams/L of soil (ISSS silt + clay) from table _____ g/L
- L. temperature correction $[(0.36 \times (J - 20^\circ \text{C}))]$ _____ g
- M. corrected silt (ISSS) and clay in suspension (K+L) _____ g
- N. grams of soil (ISSS silt + clay) in 500 mL $(M \times 0.5)$ _____ g
- O. grams of sand (ISSS) $(25 \text{ g} - N)$ _____ g
- P. percent sand (ISSS definition) $[(O/25) \times 100]$ _____ %**
- Q. specific gravity at 24 hours _____
- R. temperature at 24 hours _____ °C
- S. grams/L of soil (clay) from table _____ g/L
- T. temperature correction $[(0.36 \times (R - 20^\circ \text{C}))]$ _____ g
- U. corrected clay in suspension (S+T) _____ g
- V. grams of soil (clay) in 500 mL $(U \times 0.5)$ _____ g
- W. percent clay $[(V/25) \times 100]$ _____ %**
- X. grams of silt (USDA) $[25 - (G + V)]$ _____ g silt (USDA)
- Y. percent silt (USDA) $[(X/25) \times 100]$ _____ %**
- Z. grams of silt (ISSS) $[25 - (O + V)]$ _____ g silt (ISSS)
- AA. percent silt (ISSS) $[(Z/25) \times 100]$ _____ %**



Example

Suppose the following were recorded from the 2 minute, 12 minute and 24 hour hydrometer readings:

	Specific Gravity	Temperature
2 minutes:	1.0125	21.0
12 minutes	1.0106	21.5
24 hours	1.0089	19.5

For each hydrometer reading of specific gravity, convert to grams/liter of soil from the conversion table, and correct for temperature.

For the 2 minute reading

The specific gravity reading is closest to 1.0126, which equals 16.5 grams of silt (USDA) and clay per liter in suspension. This value is then corrected for temperature. Since the temperature reading was 1 degree higher than 20°C, add 0.36 to the 16.5 grams/liter:

$$16.5 + 0.36 = 16.86 \text{ g/L}$$

Next, multiply 16.86 g/L by 0.5 L (which was the volume of water used in the protocol) to change from grams/liter to grams:

$$16.86 \times 0.5 = 8.43 \text{ which can be rounded to } 8.4 \text{ g}$$

This is the amount of silt (USDA) and clay in suspension.

To determine the amount of USDA sand, subtract 8.4 g from the original amount of soil added in the Protocol (25.0 g):

$$25.0 \text{ g} - 8.4 \text{ g} = 16.6 \text{ g of sand (USDA)}$$

To calculate the percent of sand in the sample, divide 16.6 g by the original amount of soil added in the Protocol (25.0 g) and multiply by 100 to get percent:

$$(16.6 \text{ g}/25.0 \text{ g}) \times 100 = 66.4\% \text{ sand (USDA)}$$

For the 12 minute reading

The specific gravity reading is closest to 1.0105, which equals 13.0 grams of silt (ISSS) and clay per liter in suspension. This value is then corrected for temperature. Since the temperature reading was 1.5 degrees higher than 20°C, add 0.36×1.5 to the 13.0 grams/liter:

$$0.36 \times 1.5 = 0.54$$

$$13.0 + 0.54 = 13.54 \text{ g/L}$$

Next, multiply 13.54 g/L by 0.5 L (which was the volume of water used in the protocol) to change from grams/liter to grams:

$$13.54 \times 0.5 = 6.77 \text{ which can be rounded to } 6.8 \text{ g}$$

This is the amount of silt (ISSS) and clay in suspension.

To determine the amount of ISSS sand, subtract 6.8 g from the original amount of soil added in the Protocol (25.0 g):

$$25.0 \text{ g} - 6.8 \text{ g} = 18.2 \text{ g of sand (ISSS)}$$

To calculate the percent of sand in the sample, divide 18.2 g by the original amount of soil added in the Protocol (25.0 g) and multiply by 100 to get percent:

$$(18.2 \text{ g}/25.0 \text{ g}) \times 100 = 72.8\% \text{ sand (ISSS)}$$

Note: The amount of ISSS sand is greater than the USDA sand because ISSS considers sand to contain more fine particles, which USDA would classify as silt.

For the 24 hour reading

The specific gravity reading was 1.0089, which can be read directly off the chart as 10.5 g/L. This value represents the amount of clay per liter in suspension. The 10.5 g/L is then corrected for temperature. Since the temperature reading was 0.5 degrees lower than 20°C, subtract 0.36×0.5 from the 10.5 grams/liter:

$$0.36 \times 0.5 = 0.18$$

$$10.5 - 0.18 = 10.32 \text{ g/L}$$

Next, multiply 10.32 g/L by 0.5 L (which was the volume of water used in the protocol) to change from grams/liter to grams:

$$10.32 \times 0.5 = 5.16 \text{ which can be rounded to } 5.2 \text{ g}$$

5.2g is the amount of clay that was in the original 25 g of soil used in the Protocol.

To calculate the percent of clay in the sample, divide 5.2 g by the original amount of soil added in the Protocol (25.0 g):

$$(5.2 \text{ g}/25.0 \text{ g}) \times 100 = 20.8\% \text{ clay}$$



The amount of silt (USDA) is calculated by adding the grams of sand (USDA) to the grams of clay, and subtracting that sum from the original amount of sample (25 g):

$$16.6 \text{ g (USDA sand)} + 5.2 \text{ g (clay)} = 21.8$$

$$25\text{g} - 21.8 \text{ g} = 3.2 \text{ g silt (USDA)}$$

which can be converted to percent by dividing by 25:

$$(3.2/25) \times 100 = 12.8\% \text{ silt (USDA)}$$

The amount of silt (ISSS) is calculated by adding the grams of sand (ISSS) to the grams of clay, and subtracting that sum from the original amount of sample (25 g):

$$18.2 \text{ g (ISSS sand)} + 5.2 \text{ g (clay)} = 23.4 \text{ g}$$

$$25\text{g} - 23.4 \text{ g} = 1.6 \text{ g silt (ISSS)}$$

which can be converted to percent by dividing by 25:

$$(1.6/25) \times 100 = 6.4\% \text{ silt (ISSS)}$$

For this sample, the final result would be:

	%Sand	%Silt	%Clay
USDA:	66.4	12.8	20.8
ISSS:	72.8	6.4	20.8

Using the Textural Triangle to Determine the Textural Class Name

Soil Scientists have created classes which break the distribution of particle sizes (soil textures) into 12 categories. Textural Triangle 3 is one of the tools soil scientists use to visualize and understand the meaning of soil texture names. This textural triangle is a diagram which shows how each of these 12 textures are classified based on the percent of sand, silt, and clay in each. **Note:** these percentages are based on the USDA definition of sand and silt only.

Follow these steps to determine the textural class name of your soil sample:

1. Place a plastic sheet or tracing paper over Textural Triangle 3.
2. Place the edge of a ruler at the point along the base of the triangle that represents the

percent of sand in your sample. Position the ruler on the line that slants in the direction that the numbers are facing for percent sand.

3. Place the edge of a second ruler at the point along the right side of the triangle. Position the ruler on the line which slants in the direction that the numbers are facing for percent silt.
4. Place the point of a pencil or water soluble marker at the point where the two rulers meet. Place the top edge of one of the rulers on the mark, and hold the ruler parallel to the horizontal lines. The number on the left should be the percent of clay in the sample. Note that the sum of the percent of sand, silt, and clay should add up to 100.
5. The descriptive name of the soil sample (textural class) is written in the shaded area where the mark is located. If the mark should fall directly on a line between two descriptions, record both names.

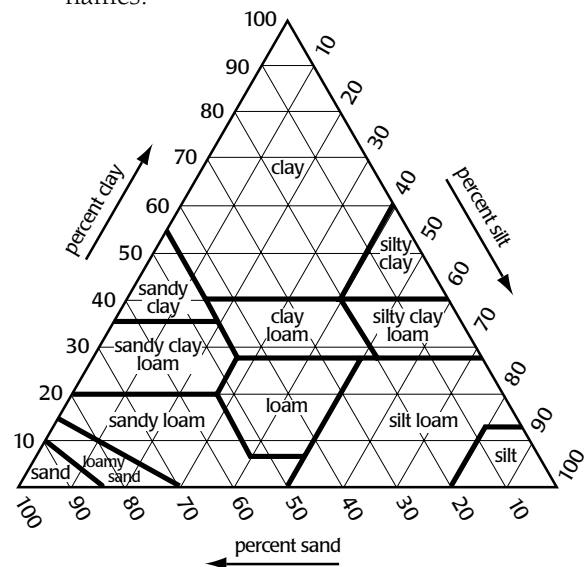


Figure SOIL-L-4: Textural Triangle 3

For the example given above, the textural class of the soil sample would be:

	%Sand	%Silt	%Clay	
USDA:	56.4	12.4	32.2	Sandy Clay Loam



Practice Exercises

Soil Texture Practice Work Sheet

Use the following numbers to determine the soil texture name using the textural triangle. When a number is missing, fill in the blanks. **Note:** the sum of percents and, silt and clay should always add up to 100 percent:

	% Sand	%Silt	%Clay	Texture Name
a.	75	10	15	sandy loam
b.	10	83	7	—
c.	42	—	37	—
d.	—	52	21	—
e.	—	35	50	—
f.	30	—	55	—
g.	37	—	21	—
h.	5	70	—	—
i.	55	—	40	—
j.	—	45	10	—

Answers: b. silt loam; c. 21, clay loam; d. 27, silt loam; e. 15, clay; f. 15, clay; g. 42, loam; h. 25, silt loam; i. 5, sandy clay; j. 45, loam.

Stoke's Law: To Calculate the Settling Time of Soil Particles

In the Soil Particle Size Distribution Protocol, the readings of the hydrometer had to be taken at a very specific time to allow either the sand or silt to settle in the cylinder. In order to determine this time for each size particle, we use an equation derived from Stoke's Law. Stoke's Law describes how fast (the velocity at which) a particle will settle as a function of its diameter and the properties of the liquid in which it is settling. Once this velocity is known, you can calculate the time required for a particle of a certain diameter to settle a given depth in water.

Stoke's Law can be written in the form of the following equation:

$$V = kd^2$$

where:

V = settling velocity (in cm/second)

d = particle diameter in cm (such as 0.2 cm - 0.005 cm for sand, 0.005 cm- 0.0002 cm for silt, and <0.0002 cm for clay)

k = a constant which depends on the liquid in which the particle is settling, particle density, the force of gravity, and the temperature ($8.9 \times 10^3 \text{ cm}^{-1} \text{ sec}^{-1}$ for soil in water at 20°C).

Example

Suppose you wanted to calculate the amount of time it would take a particle of fine sand (0.1 mm) to settle. The distance between the 500 mL mark on your graduated cylinder and the base of the cylinder is about 27 cm.

1. First, convert the diameter of the particle from mm to cm.
 $0.1 \text{ mm} \times 1 \text{ cm}/10 \text{ mm} = 0.01 \text{ cm}$
2. Using the equation above, plug in values for the diameter of the particle, square it, and multiply by the constant.

$$V = 8900 \times (0.01)^2$$

$$0.89 \text{ cm/second}$$

3. Next, divide the distance between the 500 mL mark and the base on your cylinder by the velocity calculated in step 2.

$$27 \text{ cm}/0.89 \text{ cm second}^{-1} = 30.33 \text{ seconds}$$

Thus, it would take about 30 seconds for fine sand with a diameter of 0.1 mm to settle to the base of the 500 mL cylinder.



Further Investigations

1. Feel the texture of a moist soil sample. Using Textural Triangles 1 and 2 in the *Soil Characterization Field Protocol*, determine the texture. Sand will feel gritty, while silt will feel like powder or flour. Clay will feel sticky and hard to squeeze, and will probably stick to your hand. Look at Textural Triangle 3; find the name of the textural class to which this soil corresponds. Try to estimate how much sand, silt, or clay is in the sample.
2. Practice determining the percent sand, silt, and clay in student samples using the hand “texturing” method along with Textural Triangle 3. Estimates can then be verified with the procedure outlined in the Particle Size Distribution Protocol which will tell them more quantitatively how much of each size particle is in their sample.
3. Once students feel more confident in correctly estimating texture, design a game or competition to see which students can come the closest in their estimation to the actual values determined by the settling method.
4. Develop a set of standard soil texture samples which can be used for students to practice determining soil texture. These standards should include one example of each of the twelve textural classes, with a percent sand, silt, and clay listed that was determined by the settling method.
5. Use the Stoke’s Law procedure to calculate the velocity and settling time for a particle with a diameter (in cm) in which students are interested. Be sure to use particle size in cm.

Student Assessment

Verify that students understand the relationship between particle size distribution by testing how well they can determine the textural class of unknown samples by feel. Use practice exercises, such as the ones given above to determine how well they can use the textural triangle.

Acknowledgment:

Adapted from L.J. Johnson. 1979. *Introductory Soil Science: A Study Guide and Laboratory Manual*. MacMillan Pub. Co., Inc., N.Y.